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Manassen et al.

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(54) **MEASUREMENT OF CRITICAL DIMENSION
AND SCANNER ABERRATION UTILIZING
METROLOGY TARGETS**

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CPC **G01B 11/02** (2013.01); **G06T 7/0004**
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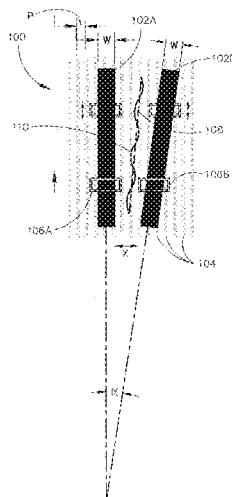
(57) **ABSTRACT**

(58) **Field of Classification Search**
CPC ... G03F 7/70633; G03F 7/0002; G03F 1/144;
G03F 7/70625; G03F 9/7088; G03F 7/7065;
G03F 9/7076; G03F 7/705; G03F 1/84;
G01N 21/956; G01N 21/9503; G01N 21/9501;
H01L 23/544; H01L 2924/00; G01B 2210/56;
Y10S 148/102; G06T 2207/30148; G06T
7/0004
USPC 356/363, 399, 401, 625, 635, 636;
382/145, 149, 151

Metrology targets and method of using the metrology targets
for measurement of critical dimension, overlay or scanner
aberration are disclosed. A target may include an unresolved
grid having a plurality of lines spaced equally apart from each
other according to a pre-determined pitch distance and at least
one resolved feature tilted at an angle with respect to the
unresolved grid. The method may identify multiple regions
of interest (ROIs) and determine a series of center points
between the ROIs as the ROIs are being shifted. Critical
dimension, overlay or scanner aberration may be calculated
by analyzing the series of center points between the ROIs.

See application file for complete search history.

19 Claims, 12 Drawing Sheets



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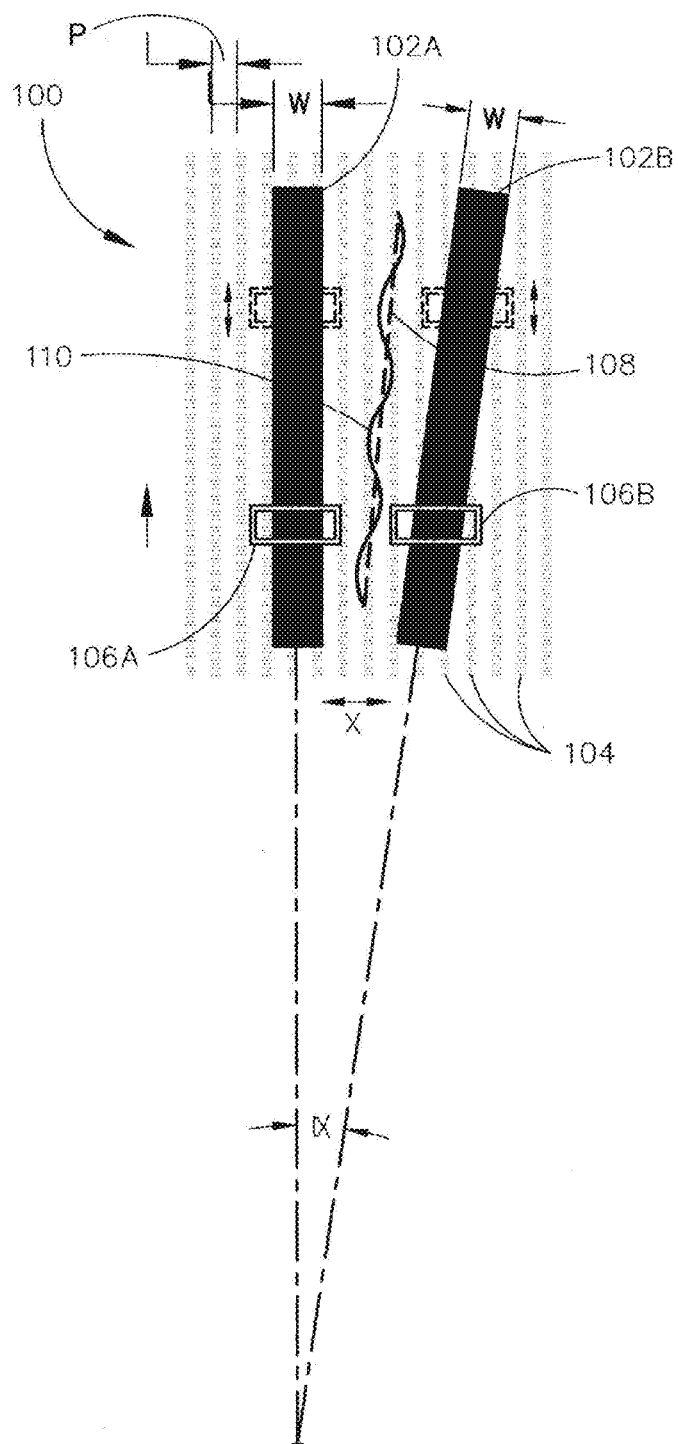


FIG. 1

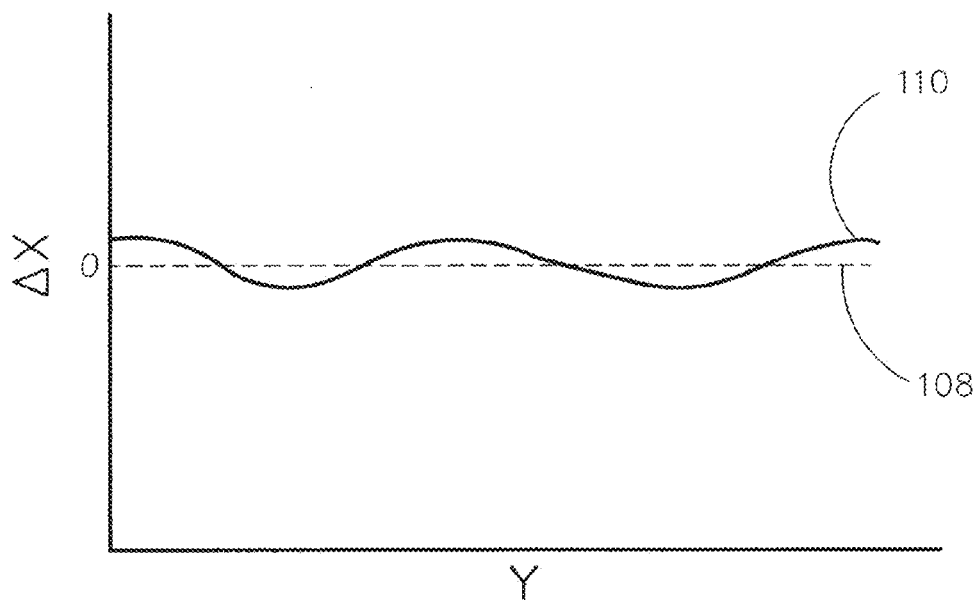


FIG. 2

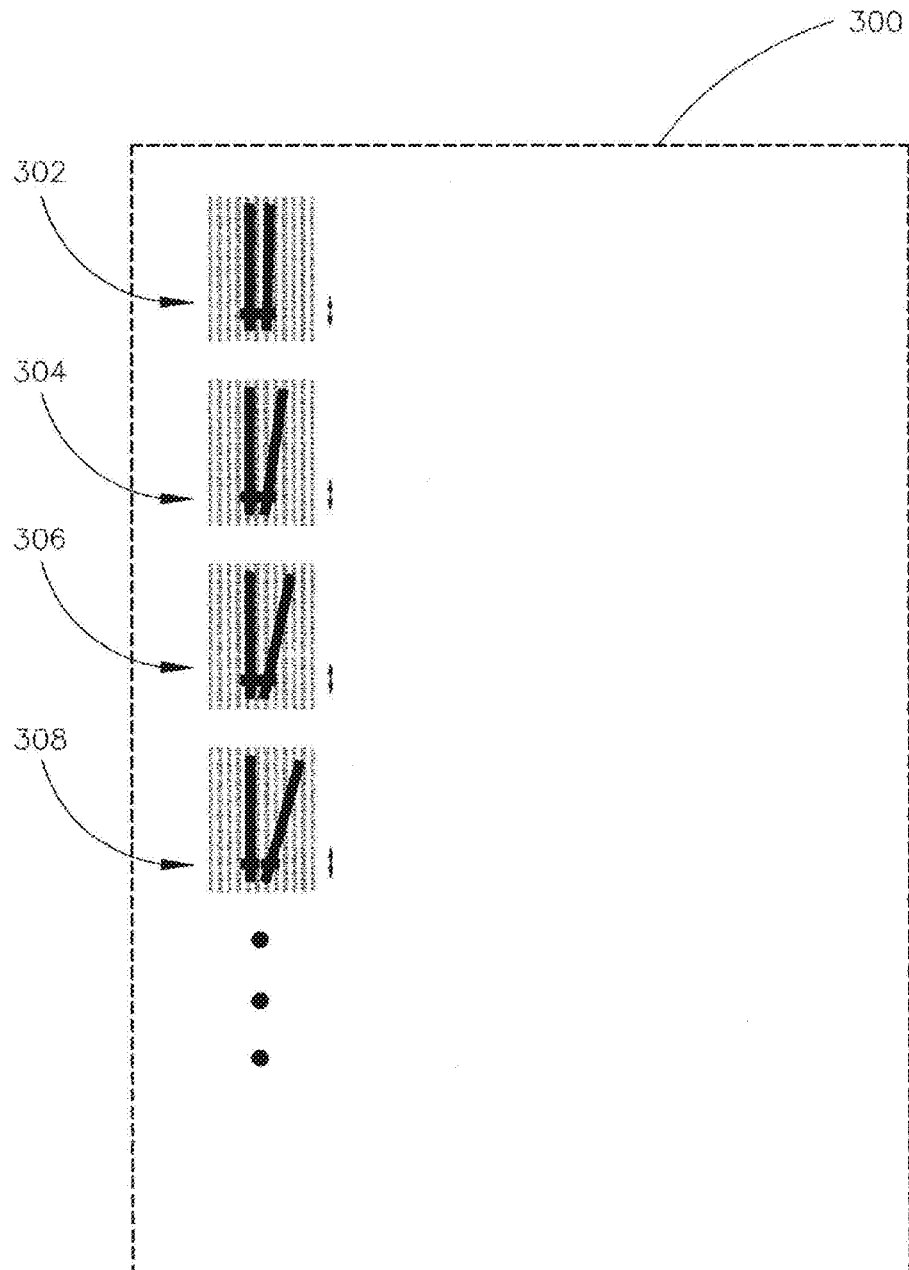


FIG. 3

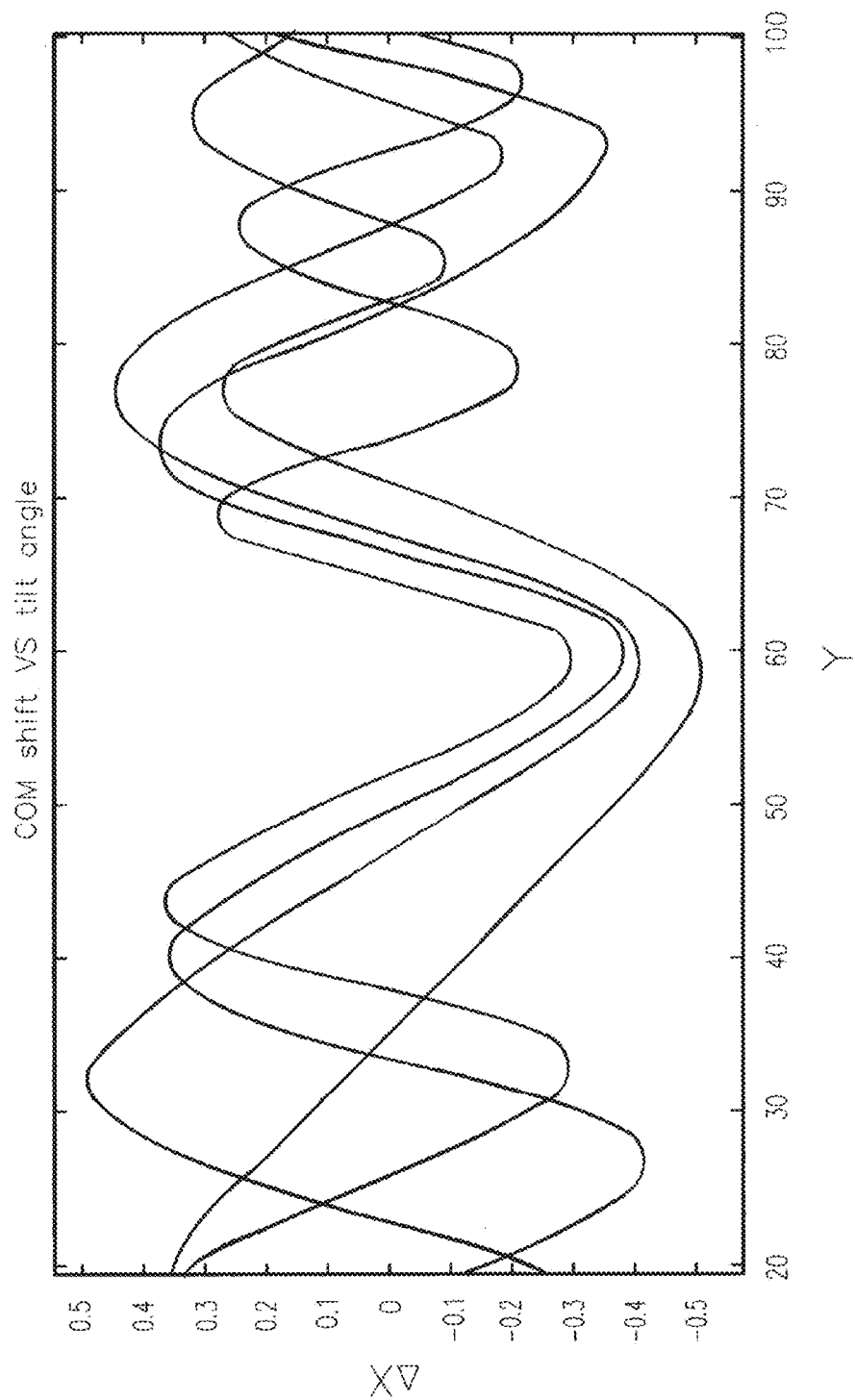


FIG. 4

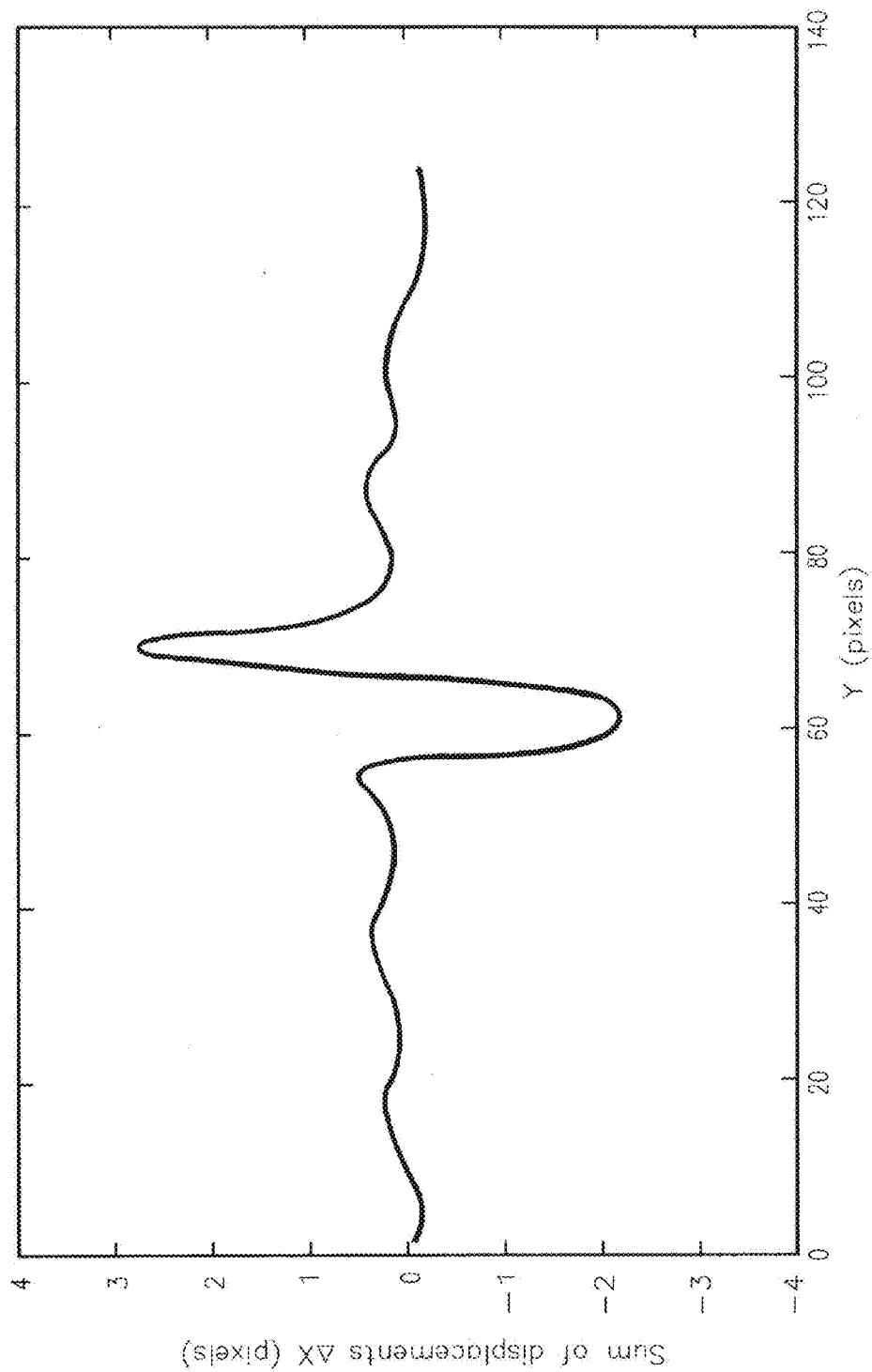


FIG. 5

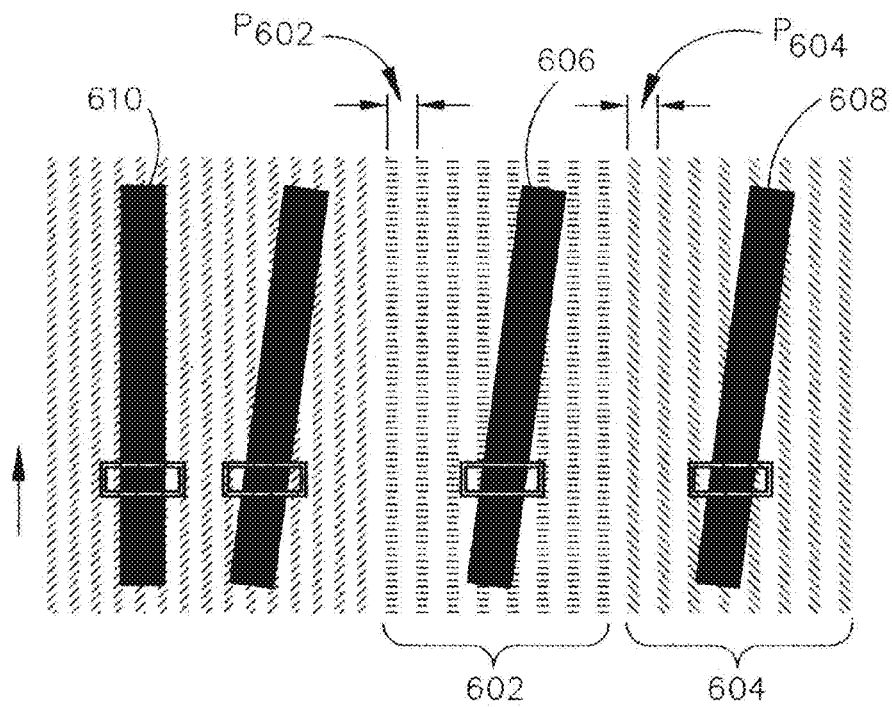


FIG. 6

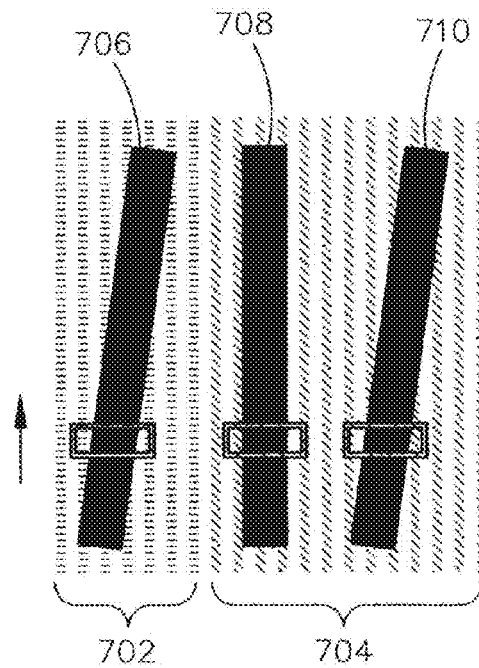


FIG. 7

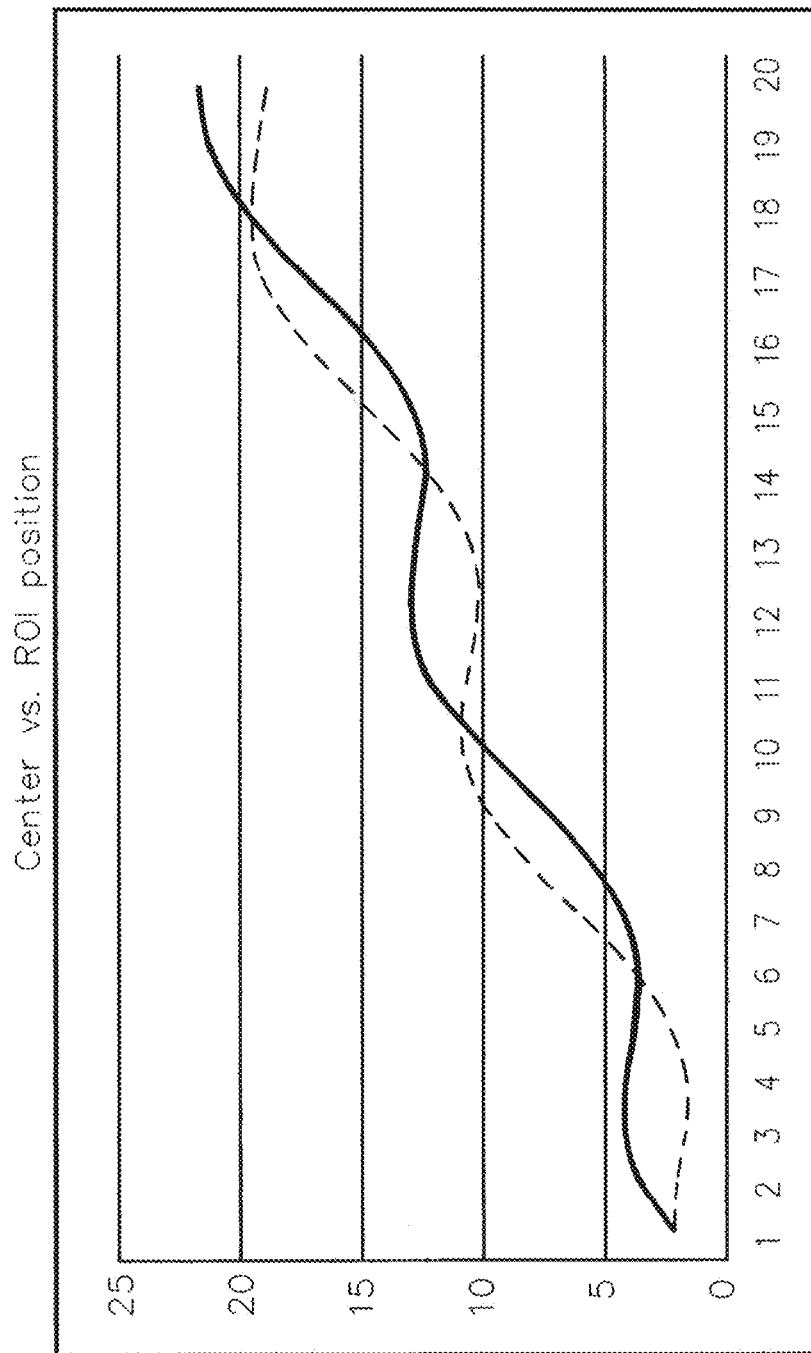


FIG. 8

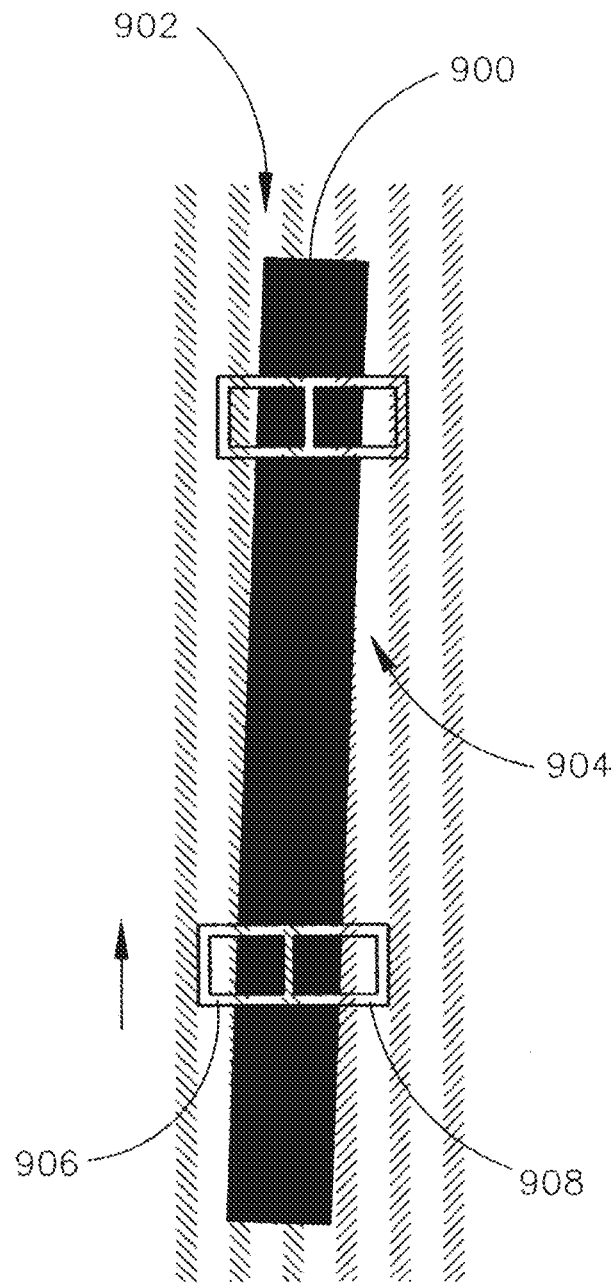


FIG. 9

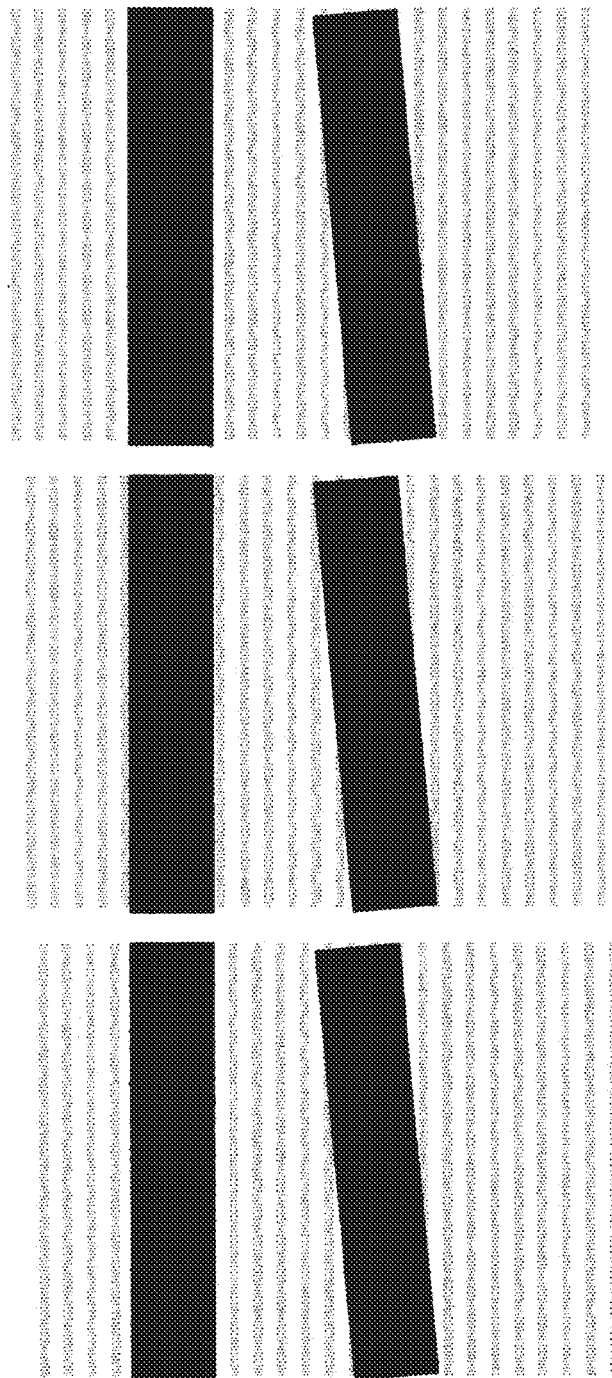


FIG. 10

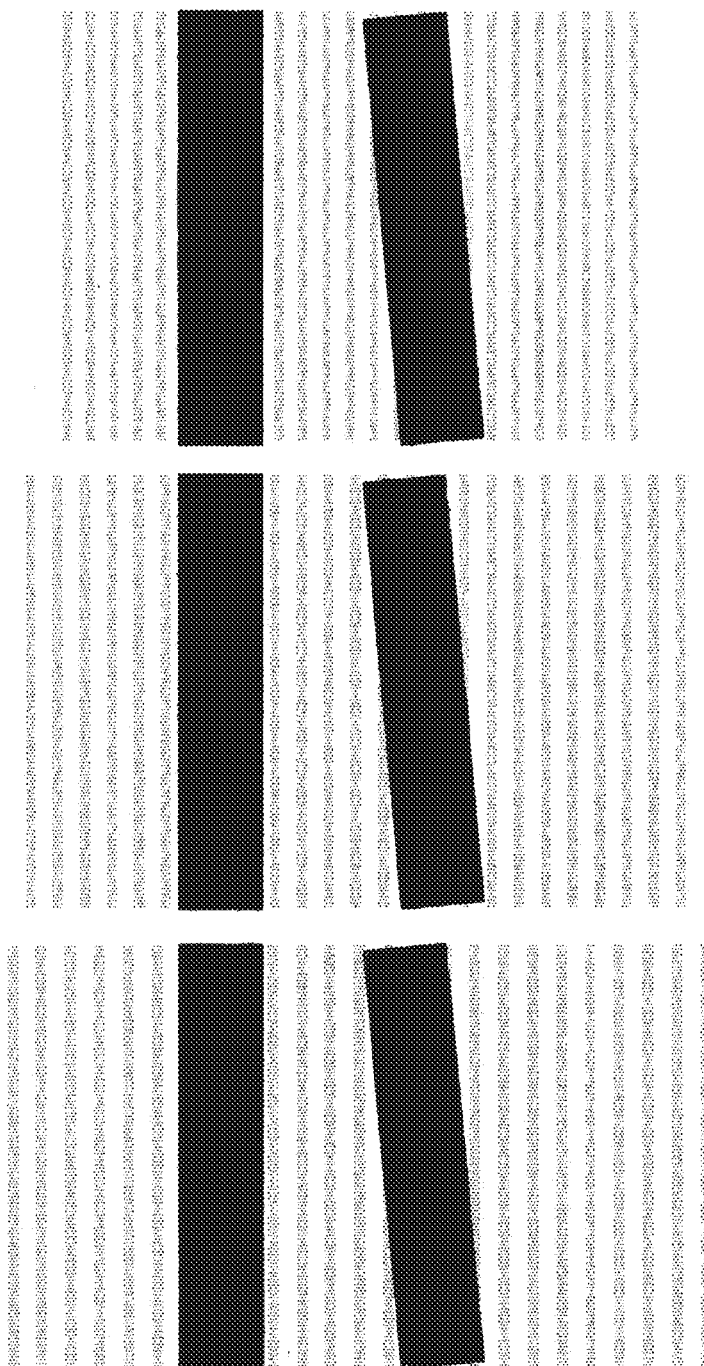


FIG. 11

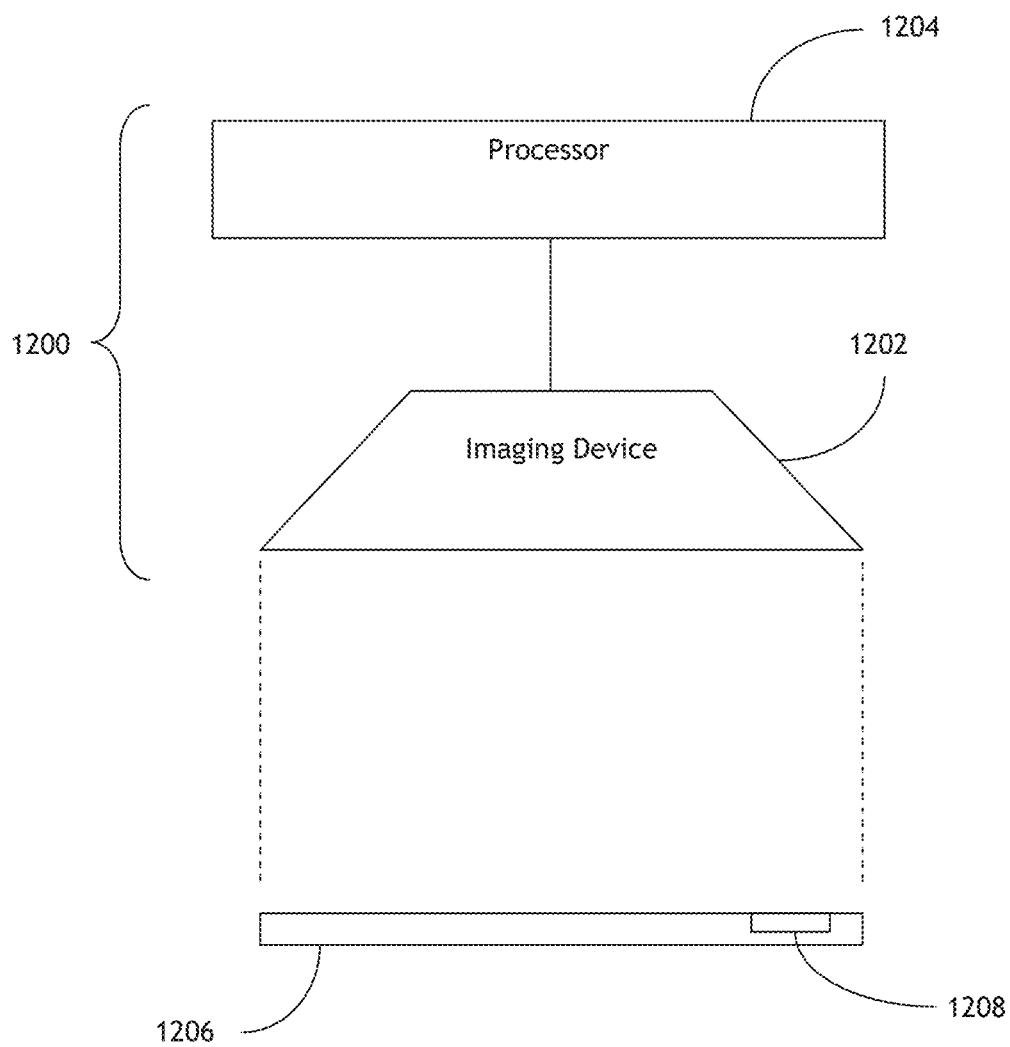


FIG. 12

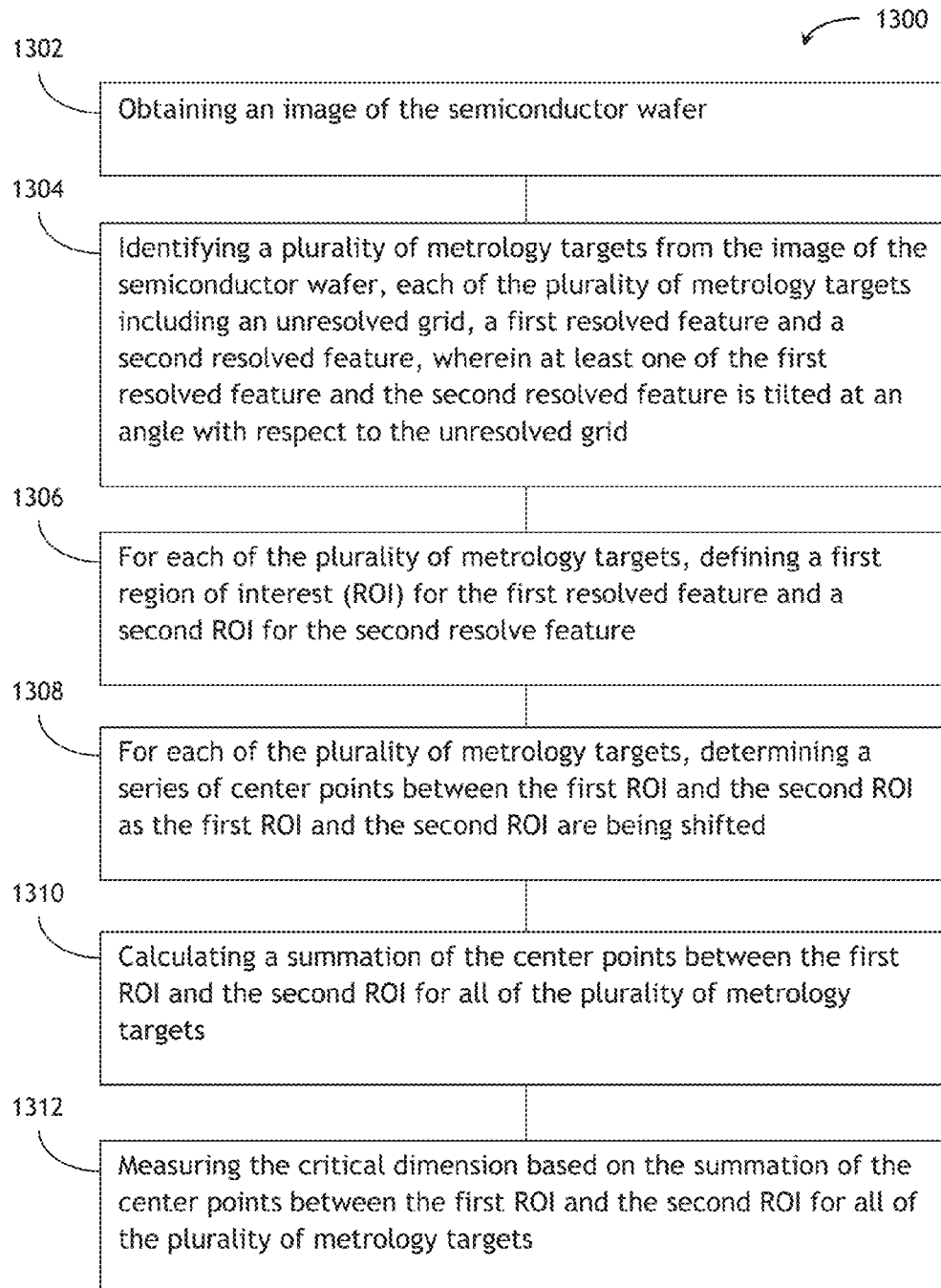


FIG. 13

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MEASUREMENT OF CRITICAL DIMENSION AND SCANNER ABERRATION UTILIZING METROLOGY TARGETS

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Application Ser. No. 61/754,755, filed Jan. 21, 2013. Said U.S. Provisional Application Ser. No. 61/754,755 is hereby incorporated by reference in its entirety.

TECHNICAL FIELD

The disclosure generally relates to the field of semiconductor fabrication, particularly to configurations of metrology targets used for semiconductor device fabrication.

BACKGROUND

Thin polished plates such as silicon wafers and the like are a very important part of modern technology. A wafer, for instance, refers to a thin slice of semiconductor material used in the fabrication of integrated circuits and other devices. Other examples of thin polished plates may include magnetic disc substrates, gauge blocks and the like. Modern semiconductor devices are typically fabricated from layers of semiconductor, conductor or isolator material printed on wafers using photolithography techniques. Providing precise positioning, alignment and critical dimension (CD) measurement during semiconductor fabrication is of critical importance.

SUMMARY

The present disclosure is directed to a method for measuring a semiconductor wafer critical dimension. The method includes: obtaining an image of the semiconductor wafer; identifying a plurality of metrology targets from the image of the semiconductor wafer, each of the plurality of metrology targets including an unresolved grid, a first resolved feature and a second resolved feature, wherein at least one of the first resolved feature and the second resolved feature is tilted at an angle with respect to the unresolved grid; for each of the plurality of metrology targets, defining a first region of interest (ROI) for the first resolved feature and a second ROI for the second resolved feature; for each of the plurality of metrology targets, determining a series of center points between the first ROI and the second ROI as the first ROI and the second ROI are being shifted; calculating a summation of the center points between the first ROI and the second ROI for all of the plurality of metrology targets; and measuring the critical dimension based on a symmetry analysis of the summation of the center points between the first ROI and the second ROI for all of the plurality of metrology targets.

A further embodiment of the present disclosure is directed to a metrology system. The metrology system includes an imaging device configured for obtaining an image of a semiconductor device. The metrology system also includes a processor. The processor is configured for: identifying at least one metrology target from the image of the semiconductor device, each of the at least one metrology target including an unresolved grid and at least one resolved feature tilted at an angle with respect to the unresolved grid; for each of the at least one metrology target, defining a first region of interest (ROI) and a second ROI; for each of the at least one metrology target, determining a series of center points between the first ROI and the second ROI as the first ROI and the second ROI

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are being shifted; and analyzing the semiconductor device based on the series of center points between the first ROI and the second ROI.

Furthermore, the present disclosure is directed to a metrology target. The metrology target includes an unresolved grid having a plurality of lines spaced equally apart from each other according to a pre-determined pitch distance. The metrology target further includes at least one resolved feature tilted at an angle with respect to the unresolved grid.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not necessarily restrictive of the present disclosure. The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate subject matter of the disclosure. Together, the descriptions and the drawings serve to explain the principles of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

The numerous advantages of the disclosure may be better understood by those skilled in the art by reference to the accompanying figures in which:

FIG. 1 is an illustration depicting a metrology target having an anchor feature and a tilted feature;

FIG. 2 is an illustration depicting the relationship between two center lines of FIG. 1;

FIG. 3 is an illustration depicting a series of metrology targets for critical dimension measurement;

FIG. 4 is an illustration depicting various center lines obtained for the series of metrology targets;

FIG. 5 is an illustration depicting a summation of the center lines of FIG. 4;

FIG. 6 is an illustration depicting a metrology target having at least two segmentations with different pitches;

FIG. 7 is an illustration depicting a metrology target having at least two segmentations with the same pitch located on different layers;

FIG. 8 is an illustration depicting the center measurement between two different tilted features relative to the anchor feature of FIG. 7;

FIG. 9 is an illustration depicting a metrology target having a single tilted feature;

FIG. 10 is an illustration depicting metrology targets with different pitch overlay;

FIG. 11 is an illustration depicting metrology targets with different pitch;

FIG. 12 is a block diagram depicting a metrology system; and

FIG. 13 is a flow diagram illustrating a method for measuring critical dimension (CD) utilizing metrology targets.

DETAILED DESCRIPTION

Reference will now be made in detail to the subject matter disclosed, which is illustrated in the accompanying drawings.

Critical dimension (CD) such as the minimum width of a feature (e.g., a line or the like) is measured during semiconductor fabrication. If the critical dimension measured is equal to or in compliance with a predefined range of acceptable dimensions, the fabrication process may proceed. On the other hand, if the critical dimension measured does not equal to or is not in compliance within the acceptable range, the fabrication process may be halted.

One embodiment of the present disclosure is directed to a method and system for measuring critical dimension (CD) and device level overlay (e.g., overlay of the segmentations,

unresolved lines or the like) utilizing a metrology target that includes both resolved features and unresolved features. Referring to FIG. 1, an illustration depicting such a metrology target **100** in accordance with an embodiment of the present disclosure is shown. More specifically, the target **100** includes both resolved features **102** and unresolved features **104**. The unresolved features **104** (e.g., shown as vertical lines in this example) are grouped closely together and are too small to be individually resolved optically by imaging tools (e.g., microscopes) of a metrology system. Such unresolved features **104** are commonly used in overlay targets, and they may also be referred to as segmentations or grids.

In addition to the unresolved features **104**, the target **100** also includes two resolved features **102** overlapping with the unresolved features **104**. More specifically, the first resolved feature **102A** is configured to be parallel to the segmentation while the second resolved feature **102B** is tilted at an angle α relative to the segmentation.

Now consider implementing imaging overlay algorithms to determine the center between the Region of Interest (ROI), identified in the figure by rectangles **106A** and **106B**, as these ROI's are being shifted in the vertical direction. In the absence of segmentation **104**, the center between the ROI's as the ROI's are being shifted should form a straight line **108** tilted towards feature **102B** at an $\alpha/2$ angle. However, in the presence of the segmentation **104**, the tilted edges of the feature **12B** overlaps with the segmentation grid **104**, producing errors that fluctuate when the ROI's **106** are shifted in the vertical direction. This result is illustrated as a curved line **110** in FIG. 1.

FIG. 2 illustrates the relationship between line **108** and line **110** of FIG. 1. The horizontal axis in FIG. 2 corresponds to the shifting of the ROI's in the Y direction in FIG. 1. The vertical axis in FIG. 2 corresponds to the difference of line **110** in comparison to line **108** in the X direction in FIG. 1. It is noted that this sinusoidal behavior of the curved line **110** is expected due to the periodical behavior of the overlay error which in turn is closely related to the pitch of the segmentation (P) and the critical dimension (CD). Therefore, targets similar to the target **100** depicted in the example above can be designed and utilized for measurement of CD.

FIG. 3 is an illustration depicting the targets for CD measurements in accordance with one embodiment of the present disclosure. As shown in FIG. 3, a plurality of targets **302** through **308** may be positioned on a semiconductor wafer **300**. Each of these targets includes two resolved features positioned at an angle as described above. In addition, the angle formed by the resolved features in each one of these targets is slightly different from the others. That is, the α angles in targets **302** through **308** are all different.

Once the image of the wafer **300** is obtained by the metrology system, each target **302** through **308** may then be identified and processed individually using various imaging overlay algorithms to determine the center between the ROI's as the ROI's are being shifted in the vertical direction. Since segmentation is present in all of these targets, fluctuating errors as illustrated above are expected for all of these targets. To illustrate this, FIG. 4 shows the center lines obtained for these targets after applying the same transformation utilized to derive FIG. 2 from FIG. 1.

Now, as illustrated in FIG. 4, it is noted that since the α angles in targets **302** through **308** are different, the center lines obtained for these targets may have different sinusoidal behaviors as the result. It is also noted that a summation of all these center lines will result in a curve as shown in FIG. 5 with clear asymmetry that is caused by CD shift. It is contemplated that the CD can be extracted from asymmetry of the periodic

sine-like function. For instance, if the CD is approximately 0.5 times the pitch of the segmentation, symmetric signal is expected. Otherwise, asymmetric behavior will grow with the ratio between the pitch and CD. The relationship between the asymmetric behavior and the ratio between the pitch and CD may be observed overtime or predetermined based on past observations, allowing the ratio between the pitch and CD to be estimated based on asymmetry of the periodic sine-like function. Once the ratio between the pitch and CD is estimated, CD can be calculated accordingly based on the pitch and the estimated ratio.

It is contemplated that to further improve the accuracy of the process described above, each of the resolved features in the targets are configured to have a width (W) that is a multiple of the segmentation pitch (P). Mathematically, $w=m \cdot p$, where m is an integer greater than or equal to 1.

It is also contemplated that while the targets **302** through **308** in the example above are depicted as separate targets printed on the wafer, they are separated merely for illustrative purposes. That is, the segmentations present in targets **302** through **308** may jointly form a unified segmentation without departing from the spirit and scope of the present disclosure. In addition, it is contemplated that the targets are not required to be arranged in a vertically fashion. That is, the targets may be arranged horizontally, diagonally, distributed at various corners or the like without departing from the spirit and scope of the present disclosure.

Furthermore, it is contemplated that the number of targets that can be utilized to facilitate CD and/or overlay measurement is not limited to 4 as depicted in the figure. The specific number of targets may change based on the desired measurement accuracy, the amount of space available on the wafer, as well as other restrictions or specifications. In addition, other parameters such as the size and shape of the ROI's, the distance between each vertical shift and the like may also vary based on specific implementations conditions. For instance, ROI's being shifted at a smaller increment (or step) may provide more accurate measurement results, but may require more processing time. It is contemplated that specific implementations may vary from the examples described above without departing from the spirit and scope of the present disclosure.

Regardless of the specific implementations, embodiments above described that critical dimension (CD) may be measured utilizing measurement targets having both resolved features and unresolved features. It is contemplated that characterizing the target after process stabilization enables monitoring of CD stability using a single image grab and implementing overlay algorithms. This enables monitoring deviations out of the process window.

It is contemplated that in addition to facilitate measurement of CD, the tilted feature designs in accordance with the present disclosure may also be utilized for other applications as well. For instance, the tilted features as described above may be utilized for providing feedback about scanner aberrations. By definition, an aberration is the collective phase tilts, at different pupil points. The light passing through each pupil point forms a specific field spatial frequency. The local phase tilt, at a specific pupil point, causes a displacement of the corresponding spatial frequency. The collection of different spatial frequencies shifts is directly related to the collection of phase tilts in corresponding pupil points and is thus directly related to aberrations. Direct measurement of displacements, per spatial frequency, will thus yield information about aberrations of the scanner. The method proposed here

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to achieve this is printing different design rule level grids, having different pitches and measurement of their relative displacement.

FIG. 6 presents a target similar to the target presented in FIG. 1, with two additional grids **602** and **604** having different pitches added for illustrative purposes. In addition to grids **602** and **604**, a resolved feature **606** overlapping with grid **602** and a similar resolved feature **608** overlapping with grid **604** are also present. It has been observed that the ROI's center measurement between features **606** and **608** relative to the anchor feature (feature **610** that is parallel to the segmentation) will yield sinusoidal lines with pitch dependent periods. The spectral phase between the periods is a direct representation of the shift per pitch, namely of scanner aberrations. Furthermore, using different resolved feature angles may yield additional information, which may be appreciated in various applications.

Another application for using tilted feature designs in accordance with the present disclosure is to measure the displacement of two unresolved grids having the same pitch but belonging to different process layers. More specifically, as illustrated in FIG. 7, resolved features **706**, **708** and **710** are positioned over unresolved grids **702** and **704**. Grid **702** may belong to one layer (wafer) while grid **704** may belong to another layer. FIG. 8 depicts the center measurement between features **706** and **710** relative to the anchor feature **708**. The phase difference between the periodic signals of the two layers indicates the overlay displacement of the two unresolved grids.

It is contemplated that while the embodiments described above all utilize two or more resolved features with at least one of them being parallel to the grid (referred to as the anchor feature), the requirement for such an anchor feature may be relaxed in an alternative embodiment. In this alternative embodiment, as illustrated in FIG. 9, both sides **902** and **904** of the resolved feature **900** are utilized for measurement rather than two resolved features as described previously. In this case, two adjacent ROI's **906** and **908** are defined and the center between the ROI's may be measurement and processed according to the techniques described above. It is understood that this alternative embodiment reduces target size and can still provide information needed to carry out the various processes as previously described.

It is further contemplated that other alternative targets may also be derived based on the tilted feature designs in accordance with the present disclosure. For instance, as shown in FIG. 10, targets with different pitch overlay may be utilized to extract the phase shift between subtargets. In addition, as shown in FIG. 11, targets with different pitch may be utilized to extract the pitch changes between subtargets. It is contemplated that the tilted feature designs in accordance with the present disclosure may also be utilized for other applications not specifically described above without departing from the spirit and scope of the present disclosure.

Referring now to FIG. 12, a block diagram depicting a metrology system **1200** capable of performing the various measurement processes described above is shown. The metrology system **1200** may include an imaging devices (e.g., a scanner, a microscope or the like) **1202** configured for obtaining images of a semiconductor device **1206** (e.g., a wafer). For instance, the imaging device **1202** may capture an aerial image (e.g., top views) of the semiconductor device **1206** and provide the image to a processor **1204** configured for processing the obtained image. It is contemplated that the metrology system **1200** may include more than one imaging device without departing from the spirit and scope of the

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present disclosure. Certain metrology systems may provide the abilities to capture both sides of the semiconductor device simultaneously.

The processor **1204** may be implemented utilizing any standalone or embedded computing device (e.g., a computer, a processing unit/circuitry or the like). Upon receiving the image from the imaging device **1202**, the processor **1204** may identify one or more targets **1208** present on the wafer **1206** and carry out the various measurement processes described above.

For instance, FIG. 13 illustrates a method **1300** for measuring critical dimension (CD) utilizing metrology targets **1208** obtained by the metrology system **1200**. Once the image of the semiconductor wafer is obtained in step **1302**, step **1304** may then identify a plurality of metrology targets from the image of the semiconductor wafer. Each of the plurality of metrology targets may include an unresolved grid, a first resolved feature and a second resolved feature. As described above, at least one of the resolved features is tilted at an angle with respect to the unresolved grid.

Step **1306** may define two ROI's for each of the plurality of metrology targets. Step **1308** then determines a series of center points between the two ROI's as the ROI's are being shifted for each of the plurality of metrology targets. It is contemplated that discrete center point locations may be determined as the ROI's are being shifted at predefined increments. The predefined increments may be very fine (e.g., at the pixel level, shifting n pixels at a time), in which case the center point locations may form a nearly continuous line. On the other hand, the predefined increments may be relatively sparse, in which case the center point locations may also be relatively sparse. It is contemplated that various curve fitting techniques may be utilized to form a continuous curve representing the center points for a particular target.

It is contemplated that the ROI's in each target may be shifted in a substantially similar manner. That is, they may all shift at the same pace. Once the center points between the two ROI's are determined for all targets, step **1310** may calculate a summation of the center points for all targets. As previously described, this summation provides a curve with clear asymmetry that is caused by CD shift, allowing step **1312** to measure the critical dimension based on this summation of the center points.

It is contemplated that the processor **1204** may also be utilized to measure scanner aberrations, displacement of two or more unresolved grids and the like. It is also contemplated that the tilted feature designs in accordance with the present disclosure may also be utilized for other applications as well without departing from the spirit and scope of the present disclosure.

The methods disclosed may be implemented as sets of instructions, through a single production device, and/or through multiple production devices. Further, it is understood that the specific order or hierarchy of steps in the methods disclosed are examples of exemplary approaches. Based upon design preferences, it is understood that the specific order or hierarchy of steps in the method can be rearranged while remaining within the scope and spirit of the disclosure. The accompanying method claims present elements of the various steps in a sample order, and are not necessarily meant to be limited to the specific order or hierarchy presented.

It is believed that the system and method of the present disclosure and many of its attendant advantages will be understood by the foregoing description, and it will be apparent that various changes may be made in the form, construction and arrangement of the components without departing

from the disclosed subject matter or without sacrificing all of its material advantages. The form described is merely explanatory.

What is claimed is:

1. A method for measuring a semiconductor wafer critical dimension, the method comprising:

obtaining an image of the semiconductor wafer;

identifying a plurality of metrology targets from the image of the semiconductor wafer, a respective metrology target of the plurality of metrology targets including an unresolved grid, a first resolved feature and a second resolved feature, wherein at least one of the first resolved feature and the second resolved feature is tilted at an angle with respect to the unresolved grid;

defining a first region of interest (ROI) for the first resolved feature of the respective metrology target of the plurality of metrology targets and a second ROI for the second resolved feature of the respective metrology target of the plurality of metrology targets;

determining a series of center points between the first ROI and the second ROI as the first ROI and the second ROI are being shifted;

calculating a summation of the center points between the first ROI and the second ROI defined for the plurality of metrology targets; and

measuring the critical dimension based on a symmetry analysis of the summation of the center points between the first ROI and the second ROI defined for the plurality of metrology targets.

2. The method of claim 1, wherein the unresolved grid includes a plurality of lines spaced equally apart from each other according to a pre-determined pitch distance.

3. The method of claim 2, wherein the first resolved feature and the second resolved feature each has a width that is a multiple of the pitch distance.

4. The method of claim 2, wherein one of the first resolved feature and the second resolved feature is parallel with respect to the unresolved grid and the other one of the first resolved feature and the second resolved feature is tilted at an angle with respect to the unresolved grid.

5. The method of claim 4, wherein the tilted angle in each particular one of the plurality of metrology targets is unique within the plurality of metrology targets.

6. The method of claim 1, wherein the first ROI and the second ROI are being shifted in substantially a same manner when the series of center points between the first ROI and the second ROI are being determined for each of the plurality of metrology targets.

7. A metrology system, comprising:

an imaging device, the imaging device configured for obtaining an image of a semiconductor device; and
a processor, the processor configured for:

identifying at least one metrology target from the image of the semiconductor device, the at least one metrology target including an unresolved grid having a plurality of lines spaced equally apart from each other according to a pre-determined pitch distance, the at least one metrology target further including at least one resolved feature tilted at an angle with respect to the unresolved grid;

defining a first region of interest (ROI) and a second ROI for the at least one metrology target;

determining a series of center points between the first ROI and the second ROI as the first ROI and the second ROI are being shifted; and

analyzing the semiconductor device based on the series of center points between the first ROI and the second ROI.

8. The metrology system of claim 7, wherein each metrology target includes at least two resolved features, one of the at least two resolved features is parallel with respect to the unresolved grid and the rest of the at least two resolved features are tilted at an angle with respect to the unresolved grid.

9. The metrology system of claim 8, wherein said at least one metrology target identified from the image of the semiconductor device includes a plurality of metrology targets, and wherein said processor is further configured for:

calculating a summation of the center points between the first ROI and the second ROI defined for the plurality of metrology targets; and

measuring the critical dimension based on the summation of the center points between the first ROI and the second ROI defined for the plurality of metrology targets.

10. The metrology system of claim 9, wherein the tilted angle in each particular one of the plurality of metrology targets is unique within the plurality of metrology targets.

11. The metrology system of claim 9, wherein the first ROI and the second ROI are being shifted in substantially a same manner when the series of center points between the first ROI and the second ROI are being determined for each of the plurality of metrology targets.

12. The metrology system of claim 7, wherein the at least one resolved feature has a width that is a multiple of the pitch distance.

13. The metrology system of claim 7, wherein said at least one metrology target identified from the image of the semiconductor device includes:

at least two unresolved grid having different pitch distances;

an anchor feature parallel with respect to the unresolved grids;

a first tilted feature tilted at an angle and overlaying with the first unresolved grid; and

a second tilted feature tilted at the same angle and overlaying with the second unresolved grid; and

wherein said processor is further configured for:

defining the first ROI for the first tilted feature;

defining the second ROI for the second tilted feature;

defining a third ROI for the anchor feature;

determining a first series of center points between the first ROI and the third ROI as the first ROI and the third ROI are being shifted;

determining a second series of center points between the second ROI and the third ROI as the second ROI and the third ROI are being shifted; and

measuring a scanner aberration based on spectral phase between the first series of center points and the second series of center points.

14. The metrology system of claim 7, wherein said at least one metrology target identified from the image of the semiconductor device includes:

at least two unresolved grid belonging to different process layers and having a same pitch;

an anchor feature parallel with respect to the unresolved grids;

a first tilted feature tilted at an angle and overlaying with the first unresolved grid; and

a second tilted feature tilted at the same angle and overlaying with the second unresolved grid; and

wherein said processor is further configured for:

defining the first ROI for the first tilted feature;

defining the second ROI for the second tilted feature;

defining a third ROI for the anchor feature;

determining a first series of center points between the 5
first ROI and the third ROI as the first ROI and the
third ROI are being shifted;

determining a second series of center points between the
second ROI and the third ROI as the second ROI and
the third ROI are being shifted; and 10

measuring a displacement of said two unresolved grids
based on phase difference between the first series of
center points and the second series of center points.

15. A metrology target, comprising:

an unresolved grid including a plurality of lines spaced 15
equally apart from each other according to a pre-deter-
mined pitch distance; and

at least one resolved feature overlapping with the unre-
solved grid and tilted at an angle with respect to the
unresolved grid. 20

16. The metrology target of claim **15**, further comprising:
at least one anchor feature parallel with respect to the
unresolved grids.

17. The metrology target of claim **15**, further comprising:
at least one additional unresolved grid. 25

18. The metrology target of claim **17**, wherein the at least
one additional unresolved grid and the first mentioned unre-
solved grid belong to different wafer layers.

19. The metrology target of claim **17**, wherein the at least
one additional unresolved grid and the first mentioned unre- 30
solved grid have different pitches.

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